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The AASERT grant supported one undergraduate and six graduate students through various periods of their studies at the University of Michigan. The supported students are all US citizens.

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Final Report

"High Power Microwave Generation from a High Current Diode"

AASERT grant F49620-97-1-0429

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Summary

Over its three year period, this AASERT grant, F49620-97-1-0429, supported a large number of undergraduate and graduate students at various levels at the University of Michigan. The supported students are all US citizens:

Sarah McGee	(Undergraduate)
Chris Peters	(Soon-to-be Ph.D; accepted offer at Lockheed-Martin)
Rex Anderson	(Ph.D candidate)
Scott Anderson	(Ph.D candidate)
William Cohen	(Received Ph.D; now at GE Lighting)
Reginald Jaynes	(Received Ph.D; now at Raytheon)
Cory Collard	(Graduate student)

Their major achievements include:

1. First applications of time-frequency analysis to a high power gyrotron and to a conventional magnetron.
2. An in-depth analysis of transient limiting current in a diode.
3. Spectroscopic analysis that identifies water as a major culprit that triggers pulse shortening in HPM sources.
4. Initiation of an experiment of multipactor on a dielectric.
5. In-depth study of AC Stark broadening and its application to HPM.

All of these supported works were closely related to the Parent DoD/AFOSR Grant No. F49620-95-1-003, "MURI Tri-University, Multidisciplinary High Energy Microwave Device Consortium." Many were conducted in close collaboration with the Air Force Research Laboratory. In fact, all of the refereed publications reported herein have an AFRL co-author.

I. Research by AASERT Students

Given below are the major activities of the AASERT students, grouped into categories. A large number of these students worked in the Intense Energy Electron Beam Laboratory under the supervision of Professor Ronald Gilgenbach. Students who have received support from this AASERT grant are highlighted in bold below.

1. Time-frequency analysis

In early 1998, the PI suggested his AASERT graduate student, **Chris Peters**, to approach Professor Bill Williams of EECS Department to learn, and to apply the time-frequency analysis to the output signal of the high power coaxial gyrotron, which was built under AFOSR/MURI support (AASERTs parent grant). The result was spectacular. It shows for the first time, with unprecedented clarity and in real time, that the frequency chirp in the output signal is correlated with the diode voltage fluctuations. This powerful diagnostic opens up a new way to analyze pulse shortening, mode competition, mode hopping, intermodulation, noise and unwanted frequencies, etc. This work was reported in the paper:

(a) **C. Peters**, **R. L. Jaynes**, Y. Y. Lau, R. M. Gilgenbach, W. J. Williams, J. M. Hochman, **W. E. Cohen**, J. I. Rintamaki, D. E. Vollers, and T. A. Spencer, "Time-frequency analysis of modulation of high power microwave by e-beam voltage fluctuations", Phys. Rev. E **58**, 6880 (1998).

Colleagues at AFRL/Phillips Lab (Tom Spencer, John Luginsland, Kyle Hendricks, and others) collaborated with us in applying this new technique to their HPM devices such as MILO and RKO. Chris Peters is scheduled to defend his PhD thesis shortly.

(b) **Christopher Wayne Peters**, "Time-Frequency Analysis of High Power Microwave Sources," PhD dissertation, University of Michigan (to be defended on December 1, 2000).

Most recently, graduate student **Scott Anderson** has applied the time-frequency analysis to the conventional microwave oven magnetron in an

attempt to understand the noise and unwanted frequency in crossed-field devices.

2. Virtual cathodes driven by electromagnetic transients

AASERT undergraduate **Sarah McGee**, working closely with Dr. John Luginsland of AFRL/Phillips Lab, concluded her extensive computer studies on the importance of self magnetic field and of relativistic effects in the determination of the limiting current in a diode, using both OOPIC and MAGIC codes. Many unsuspected phenomena were discovered, even when the diode voltage is as low as 30keV. For example, they found that virtual cathodes may be triggered inductively during the current rise-time (because of Ldi/dt). This transiently-induced virtual cathode persists indefinitely, long after the diode current reaches its steady state value, even if that steady state value is *below* the limiting current that is determined from a DC theory. This finding has implications on fast switching diodes and on emission algorithms used in computer simulations. This work is published in

(c) J. L. Luginsland, **S. McGee**, and Y. Y. Lau, Electromagnetic Limiting Current, SPIE Vol. 3158, Intense Microwave Pulse V (August, 1977).

(d) J. W. Luginsland, **S. McGee**, and Y. Y. Lau, "Virtual Cathode Formation Due to Electromagnetic Transients," IEEE Trans. Plasma Sci., **26**, 901 (1998).

3. Optical spectroscopy interpretations

Another AAERT-supported graduate student, **William Cohen**, performed extensive optical diagnostics on the rectangular cross section gyrotron, another project supported by the MURI (parent) grant. The following scenarios of pulse shortening emerged from the thousand shots. Electron beam desorbs and dissociates water vapor from the walls of the tube and collector. Fast hydrogen neutral atoms rapidly fill the waveguide. The HPM breaks down the hydrogen into a dense plasma, terminating the microwave. This work shows the critical importance of water in pulse shortening. He has recently completed his Ph.D thesis on this topic:

(e) **William Erwin Cohen**, "Optical Emission Spectroscopy and Effects of Plasma in High Power Microwave Pulse Shortening Experiments," Ph.D dissertation, University of Michigan (2000).

(f) R. M. Gilgenbach, J. M. Hochman, **R. L. Jaynes, W. E. Cohen**, J. I. Rintamaki, **C. W. Peters**, D. E. Vollers, Y. Y. Lau, and T. A. Spencer, "Optical spectroscopy of plasma in HPM pulse shotening experiments driven by a microsecond e-beam," IEEE Trans. Plasma Sci. **26**, 282 (1998).

4. <u>Large orbit gyrotron</u>

Another graduate student, **R. L. Jaynes**, also recently completed his Ph.D thesis:

(g) **Reginald Lamar Jaynes**, "Generation of High Power Microwaves in a Large Orbit Coaxial Gyrotron," Ph.D dissertation, University of Michigan (2000).

He built the large orbit coaxial gyrotron in Gilgenbach's lab and was involved in virtually all HPM experiments during his tenure as a graduate student, as further exemplified in the following publications.

(h). J. M. Hochman, R. M. Gilgenbach, **R. L. Jaynes**, J. I. Rintamaki, Y. Y. Lau, **W. E. Cohen**, **C. W. Peters**, and T. A. Spencer, "Polarization Control of Microwave Emission from High Power Rectangular Cross-Section Gyrotron Devices," IEEE Trans. Plasma Sci., **26**, 383 (1998).

(i). **R. L. Jaynes**, R. M. Gilgenbach, **W. E. Cohen**, **C. W. Peters**, J. M. Hochman, N. Eidietis, J. I. Rintamaki, Y. Y. Lau, and T. A. Spencer, "Velocity Ratio Measurement, Diagnostics and Simulations of a Relativistic Electron Beam in an Axis Encircling Gyrotron," IEEE Trans. Plasma Sci., **27**, 136-138 (1999).

(j). **R. L. Jaynes**, R. M. Gilgenbach, **C. W. Peters, W. E. Cohen**, M. R. Lopez, Y. Y. Lau, W. J. Williams, and T. A. Spencer, "High Power, Large-Orbit, Coaxial Gyrotron Oscillator Experiments", IEEE Trans. Plasma Sci. (June 2000 issue).

5. <u>Experiment of multipactor on dielectric</u>

Another graduate student, **Rex Anderson**, will devote his Ph.D thesis on an experiment of multipactor on a dielectric, under the close supervision of Profs. Ward Getty, Mary Brake, and Ron Gilgenbach. [They have been all very enthusiastic and supportive of this multipactor experiment, thus prompting the PI to use this AASERT fund as seed money to get Rex Anderson's experiment started.] This is what they come up with, given our very limited resources: The experiment consists of a small brass microwave cavity in a high vacuum chamber. The dielectric is cut into a thin disc with a diameter slightly less than the inner diameter of the cavity. It is slid into place inside the cavity where the electric field is greatest in magnitude. The mode in the cavity is TE_{111}, which provides the desired RF electric field that is parallel to the dielectric surface. The charging field on the surface of the dielectric is seeded by the bombardment of electrons from a thermionic cathode located on the opposite end of the cavity. The vacuum system is capable of base pressures in the 10^{-7} Torr region. The microwave source is pulsed at 2.45 GHz with 4.5 kW of power. Areas of study will include operating parameters that multipactor occurs on different dielectric materials, outgassing of the dielectric surface, detuning of the cavity, and ways to prevent, or extinguish multipactor. Diagnostics include various probes to measure current and electric fields, and phosphor painted on the dielectric surface to allow visual detection of multipactoring. The status of this experiment was recently presented at the GEC Conference:

(k). **R. Anderson**, W. Getty, Y. Y. Lau, M. Brake, A. Valfells, and R. M. Gilgenbach, "Design of a multipactor experiment on a dielectric", GEC Conference (Houston, TX, October 2000).

Currently, this experiment is supported by the PI's DoE grant.

6. AC Stark effect as a diagnostic of HPM electric field

Most recently, graduate student **Scott Anderson** was working with the PI on using the AC Stark effect to infer the rf electric field (i.e., rf power) in HPM devices. An efficient algorithm is being devised. The work is in progress. If successful, it will be of great use to the HPM community as a novel diagnostic of the rf electric field strength.

II. Accomplishments

During this funding period, the PI received these recognitions:

Y. Y. Lau received the 1999 IEEE Plasma Science and Applications Award at the IEEE International Conference on Plasma Science (June 1999, Monterey, CA). Multipactor discharge was a major topic in his Plenary Award Lecture, entitled, "Simple models on some nasty problems on beams and plasmas."

Y. Y. Lau was re-appointed as an Associate Editor of Physics of Plasmas, for another 3-year term (2000 – 2002). He was a Guest Editor for the IEEE Transactions on Plasma Science, Special Issue on High Power Microwave Generation (June, 1998 issue).